# An Architecture Design Project: Building Understanding

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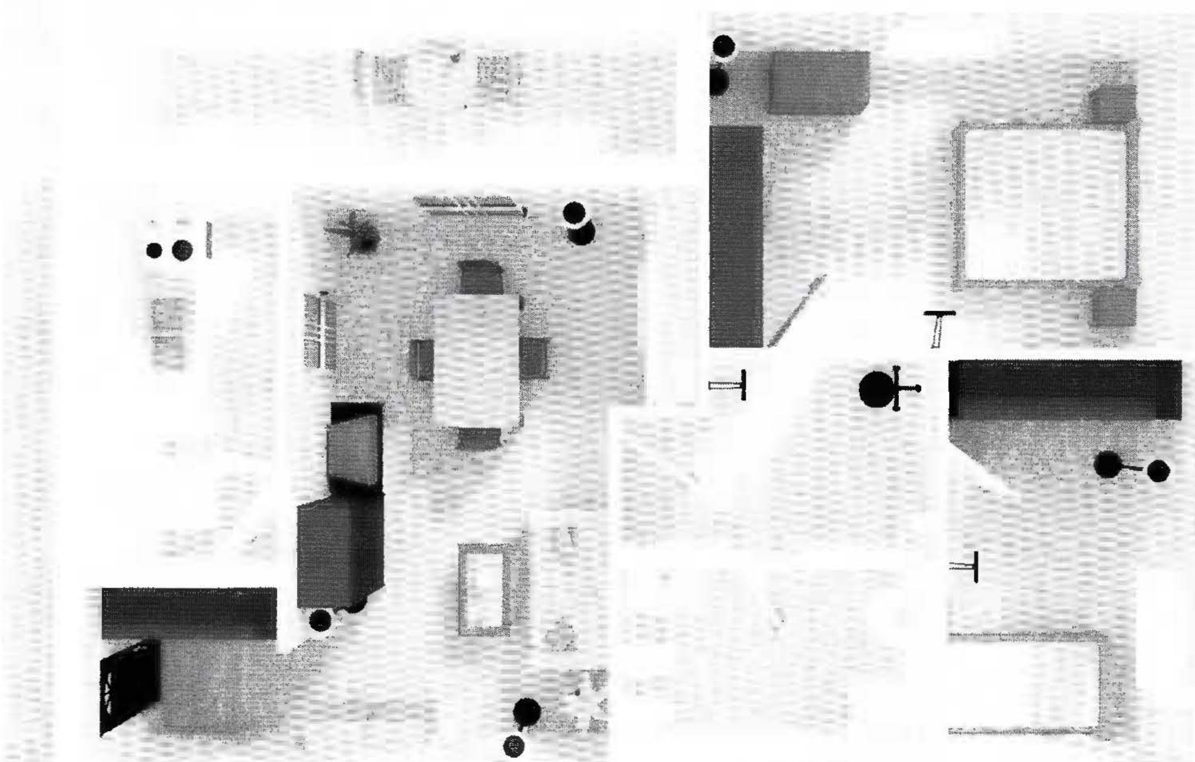
*Seventh-grade students investigate area, surface area, volume, proportional thinking, number sense and technology.*

Middle school students need relevant, meaningful contexts to apply emerging mathematical ideas. In this project, through the context of an architecture investigation, seventh-grade students engaged in mathematics involving area, surface area, volume, ratios and proportional thinking, number sense, and technology integration. Students, working in mixed-ability groups, were given an occupant scenario, which they used to build a home designed to meet the needs of their unique residents. After initial drawings of plans followed by critiques from a practising architect, they finalized designs and carried out mathematical tasks related to their plans. As a culminating event, student groups presented their home plans to local stakeholders, including peers, an architect who designed the school building, the district's mathematics curriculum specialist, and teachers from the school, who provided valuable feedback. Throughout the project, students completed a math log to record their mathematical thinking. Our project was tested in two seventh-grade classes taught by one of the authors.

This project aligns primarily to one cluster in the seventh-grade geometry domain of the Common Core State Standards for Mathematics (CCSSM), which is to "solve real-life and mathematical



problems involving angle measure, area, surface area, and volume" (CCSSI 2010, 7.G.6, 50). The appendix (online) describes specific alignment to both sixth- and seventhgrade content standards as well as connections to solving real-world and mathematical problems in ways that connect to two seventh-grade domains: ratios and proportional relationships, and the number system. Additionally, this project addresses two of the Common Core's eight Standards for Mathematical Practice (SMPs).

SMP 4, Model with mathematics, states that "Mathematically proficient students can apply the mathematics they know to solve problems arising in everyday life, society, and the workplace" (p 7). Students also accessed SMP 5, Use appropriate tools strategically, employing technology to build their architectural designs. Furthermore, NCTM's *Principles to Actions: Ensuring Mathematical Success for All* describes eight high-leverage Mathematics Teaching Practices that guide teachers to effectively implement instruction. This activity provides an example of Practice 1 and Practice 7:

- "Implement tasks that promote reasoning and problem solving." *As students engage in this project, which allows for a variety of solution strategies, they must reason mathematically.*
- "Support productive struggle in learning mathematics" (NCTM 2014, 10). *Students authentically wrestle with using design technology to create home plans that are responsive to the needs of occupants as well as conforming to established building constraints.*

**Figure 1.** *Students had to work within these project constraints.*

Directions: The following is a list of constraints that your group needs to be aware of when designing your home. Your design must have the following:

- One story—no basement
- Between 2,000 square feet, ±20 per cent
- At least 15 feet from the road
- At least 15 feet from all property lines
- Front door
- Back door
- Kitchen
- At least 1 bathroom
- Use standard conventional dimensions for doorways, hallways, ceilings and so forth.
- A closet for each bedroom
- Do not consider electricity, heat and plumbing

Because this transdisciplinary project was an authentic convergence of design, art, aesthetics, engineering, community planning and mathematics, the teacher had to move between the realm of the mathematics and other subjects to truly address objectives from each field of study. Transdisciplinary teaching supports students in

> exploring content areas by foregrounding a problem or issue using multiple inquiry processes, which naturally connect the disciplines through the problem to be solved. (Herro and Quigley 2016, 2)

You will notice that as a truly integrated project, it is neither a mathematics project that touches on some small aspect of engineering nor an art project that touches on a trivial aspect of mathematics—it is a blend. Therefore, in some sections of the work described below, the focus will, for example, shift to design. We have found it important in our work that middle school students witness how learning can truly cross over into multiple disciplines, as this is what they will experience in the real world.

## Introduction and Brainstorming

On the first day of this exploration, students watched a video in which the architect on our author team provided home-design constraints (see Figure 1). Some elements of community planning and design were easily understood, but some required more detail, such as the description of public versus private space. To get students thinking, the architect asked, "Where would be the ideal location to position the bathroom in the home?" and "What distance from the front door of your house do you want to make your bedroom?" When considering the connections between interior and exterior spaces, he asked students to reason about "Which actively used rooms might have windows to look out into the neighbourhood and "What would you want people to see if they looked into your house from the street."

Next, students were placed in groups and given a unique occupant scenario card (see Figure 2) and quiet time to individually brainstorm and create initial conceptual plans for their homes (see Figure 3 for an example). At this point, students were not yet focused on the precise dimensions of each room. Day 1 concluded with students working in groups to discuss the responsiveness of their individual sketches to the hypothetical residents' needs and to work on questions in their math logs (see Figure 4).

**Figure 2**. *Each student group received a unique occupant scenario card.*

**Scenario A:** Your challenge is to design the ideal space for a family of four. This family includes a mom and dad in their 40s, a daughter age 7, and a son age 9. They also have a pet pig. Mom likes to do yoga, dad likes watching sports, the daughter wants to be a scientist and the son loves to play basketball. Their pet pig needs a place to stay cozy outside, but the family would also like a designated space in the house where the pig could stay.

**Scenario B:** Your challenge is to design the ideal space for a newlywed couple. They have two cats and a cockatiel. She needs an office space in the house, and he wants a man cave. He also has a motorcycle.

**Scenario C:** Your challenge is to design the ideal space for three elderly sisters. One sister has a walker, and one sister loves to cook. They all think they are the "ruler of the house" and deserve the biggest space.

**Scenario D:** Your challenge is to design the ideal space for three college students—two males and a female. The female wants her privacy. All three of them are avid road bikers and have a combined five bikes and accessories.

**Scenario E:** Your challenge is to design the ideal space for a family of three, soon to be four. The couple already has a four-year-old boy and just found out they are expecting another boy. They are very musically inclined, and they want the four-year-old to learn how to play the piano.

**Scenario F:** Your challenge is to design the ideal space for a couple who have grown children. Although they have been empty nesters for the last five years, they recently found out that their daughter and granddaughter, age 13, are moving back in. The teenager is not excited about moving in with her grandparents.

**Scenario G:** Your challenge is to design the ideal space for two brothers. One plays the drums, and the other is an exercise enthusiast and has lots of equipment, including weights. Both work out of the home with technology jobs that require workspace and the ability to e-conference.

**Scenario H:** Your challenge is to design the ideal space for a young couple with newborn twin girls. Both parents work long hours, so the husband's mom is moving in with them to help out. The couple wants to make sure the husband's mom has a small kitchenette in or near her bedroom.

**Scenario I:** Your challenge is to design the ideal space for a single man.

In question 1, students tapped into empathy in considering the occupants' needs. Two student responses highlight how the scenarios played a critical role in their design decisions for the proposed residents:

> Our occupants had 5 bikes, so we knew that we'd need a garage. Also, since the people are college students, we inferred they would require study space. The girl got her own room for privacy, and we had to incorporate a large living room for parties. Since there are 3 people, they would probably need a laundry room for all their clothes.

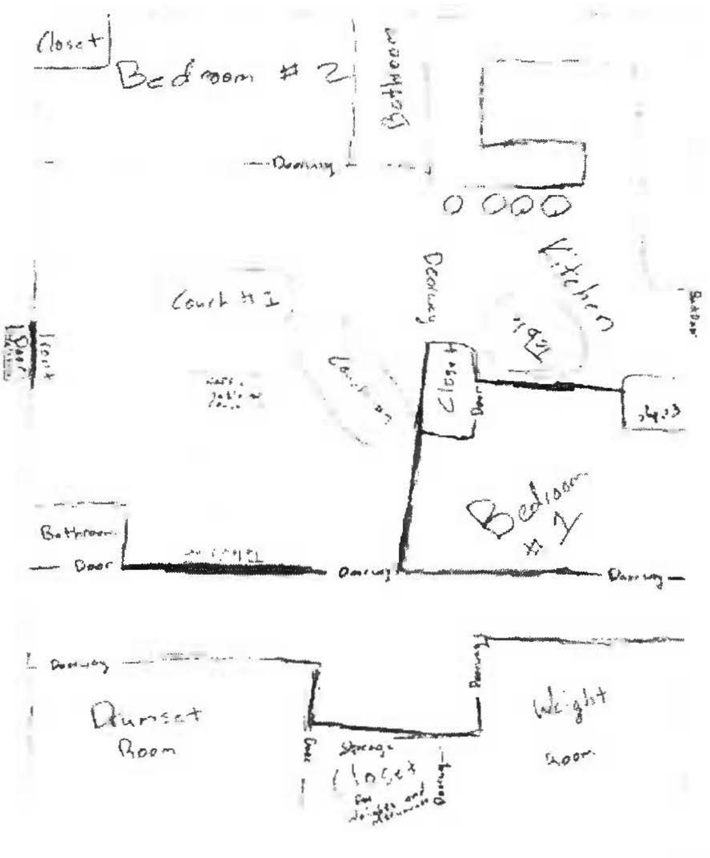
> The occupant of the house needs includes the man that lives there who is handicapped and enjoys gardening. This scenario influences our design choices because we can't use stairs and there has to be a big backyard.

Question 2 required students to explore the mathematics as they thought through such project constraints (see Figure 1) as room dimensions and square footage. Students were challenged by how to handle the "extra inches" in the calculations of square feet. When a measure was 18 ft 10 in by 23 ft 11 in, they realized after discussion that finding the area was made easier by converting those measures to decimals. Students used the Internet to find standard conventions for such dimensions as length and width of doors, width of a hallway and area of a laundry room.

## Creating SketchUp Designs

For two days, student groups fine-tuned their original paper-and-pencil designs using SketchUp (2016) software to simulate the authentic work of an architect. Students reviewed several tutorials about SketchUp to help them understand how to effectively use such features as the dimension tool (find tutorials under the SketchUp website's Learn tab). Groups' SketchUp designs were based on the best ideas from each individual sketch. At the end of these two days, student group designs were sent electronically to the architect, who then provided written feedback to strengthen their final home designs (see Figure 5). SketchUp is free software that can be downloaded onto either Windows or Mac. Teachers may also wish to explore other free software, including GeoGebra or Tinkercad design software. Although creating the group designs by using software that helps students visualize the house three dimensionally has many advantages, this project can be completed effectively with group designs constructed using paper and pencil.

**Figure 3**. *This sample student plan involved scenario G.*




Although creating SketchUp designs were a key part of this project, the mathematics could get lost without explicit attention to focusing on students' thinking. Therefore, students were also responsible for completing questions 3–6 in their math logs. Question 3 sparked the most interesting discussions. Some groups had difficulty recalling the meaning of surface area, which provided an opportunity to review this key concept. For some groups, we brought out a three-dimensional (3-D) solid of a rectangular prism and asked students to imagine it as a bedroom: "What parts of this figure would we need to paint if we were painting the walls and ceiling?" and "How could you determine how much paint you need?" Although some students immediately wanted to use the traditional algorithm for finding surface area, instead, we asked students to consider "What makes sense?" as highlighted in the following typical discussion:

*Teacher:* What do you really need to paint in this bedroom?

*Student 1:* Four walls and the ceiling.

*Teacher:* How is this different from finding the overall surface area of a 3-D solid?

*Student 2:* We don't need to paint the floor; we only need to paint five sides total.

*Teacher:* Is there anything else we need to account for?

*Student 3:* The door and windows.

*Teacher:* Good thinking; how could your group account for the fact that you aren't painting the door or windows?

*Student 1:* We could find the area of this wall (the one across from the wall with the door) and then subtract the area of the door.

Some students also started to confuse surface area and square footage. While calculating the surface area of the bedrooms, students referred to the original list of constraints and started to panic, thinking that because their surface area was more than 2,000 square feet that they had exceeded the constraint of 2,000 square feet ± 20 per cent for the house. Again, using the 3-D solids as well as the classroom space as examples, we held discussions about the difference between surface area (such as in question 3) and square footage of a room or entire home.

As students continued to test and retest whether their overall home design was between 2,000 square feet ± 20 per cent, we found it interesting how students made sense of ± 20 per cent. The conversation below displays evidence of students' mathematical sense making:

*Student 1*: What is "± 20 per cent"?

**Figure 4**. *Students worked on their Math Logs throughout the project.*

1. Describe your consideration of occupant needs. How did your scenario card influence your design decisions?
2. What will be the dimensions of your actual house? The total square footage?
3. Suppose you wanted to paint the walls and ceiling of all the bedrooms. What is the surface area of these spaces? Explain your thinking.
4. You may consider getting air conditioning and base the size of the air conditioner on the amount of space it must cool. What is the volume of each room in your house?
5. Formulate a rationale on how and why your home fits the needs of your occupants. What particular features did you include as a response to your scenario card?
6. As you work on your prototype in SketchUp, how did you use the SketchUp tools? Describe your thinking using mathematical words, drawings, and symbols.
7. Who will be responsible for each part of the presentation? What questions should you be prepared to answer (e.g., consider your audience: the architect, the principal, and so on)?
8. During your presentation, how will you explain to the stakeholders the important mathematics related to your design?
9. How did the feedback from the architect change your thinking about your design? Be specific.
10. Architects often consider the surface area to volume ratio of a house using the surface area of the home exterior and the volume of the entire house. What is this ratio for your group's house? Show all work for finding both the exterior surface area and volume, as well as the ratio.
11. What ideas did you gain from being critiqued by the stakeholders and fellow classmates?
12. Describe the challenges you faced adhering to the constraints of the project.
13. What essential mathematics must architects know to do their job?
14. If you were hiring an architect to design your house, what mathematics questions would you ask to determine if he or she was qualified for the job?

*Teacher:* It means it is acceptable to have 20 per cent more or 20 per cent less than the 2,000 square feet.

*Student 1:* How would I know how much that is?

*Teacher:* Good question. How would you figure that out?

*Student 2:* Could we try 2,000 multiplied by 20/100?

*Student 3:* Oh, that would be 400 because 4 + 4 + 4 + 4 + 4 = 20, so 20 per cent of 2,000 would be 400.

*Teacher:* Interesting; so what range of square feet could you have?

*Student 3:* 2,400.

*Teacher:* I agree that is the max.

*Student 1:* Oh, so you could have anywhere from 1,600 to 2,400 square feet.

*Teacher:* Let's go back to the idea of 4 + 4 + 4 + 4 + 4 = 20, so 20 per cent of 2,000 would be 400." Can you say more about your thinking here?

*Student 3:* Out of 100 per cent, which is five 20 per cents, so I knew out of 20, there are five 4s. The 4s and the 20s would be the same thing as the 400 and 2,000. So 400 + 400 + 400 + 400 + 400 = 2,000.

*Teacher:* What do you call a relationship that is not the same but that has the same scale (trying to link their thinking to proportional relationships).

*Student 2:* This is like simplifying a fraction.

*Student 3:* When you take the fraction

$$\frac{400}{2,000} = \frac{4}{20}$$

As students grappled with these various mathematical concepts, they were able to work through question 3 (see Figure 6). As they moved to the next question, students had less difficulty finding the volume. As students worked on question 5, they fine-tuned their previous ideas from question 1. On question 6, students described their selection and use of tools (see Figure 7), which connected mathematics, art and engineering design concepts.

## Preparing for Project Culmination

Students spent two days completing these tasks: addressing architect feedback to finalize their home designs, responding to questions in their math logs and creating their presentations. Architect feedback was in the form of general considerations for design, in every case resulting in students improving their home design through multiple iterations. For example, one group received feedback about their kitchen being only about six feet wide. After we prompted this group to get a yardstick and measure six feet, they quickly realized that this measurement "won't work because you need enough space for counters, an oven and to walk through past someone." Architect feedback also focused on design and proportional thinking (see Figure 8), causing students to reconsider and improve some of their previous responses in their math logs.

Once designs were finalized, groups worked to complete questions 7–14 in their math logs. Some questions were designed to help organize students' presentations, and other questions called for students to summarize changes made from the architect's feedback. Question 10 allowed us to formatively reassess students' understanding of surface area and volume; we found that as the week progressed, students had gained a better conceptual understanding of these ideas.

Finally, students created PowerPoint presentations guided by a template (see online) that included needed presentation components.

**Figure 5**. *The architect gave students feedback to strengthen their final home designs.*

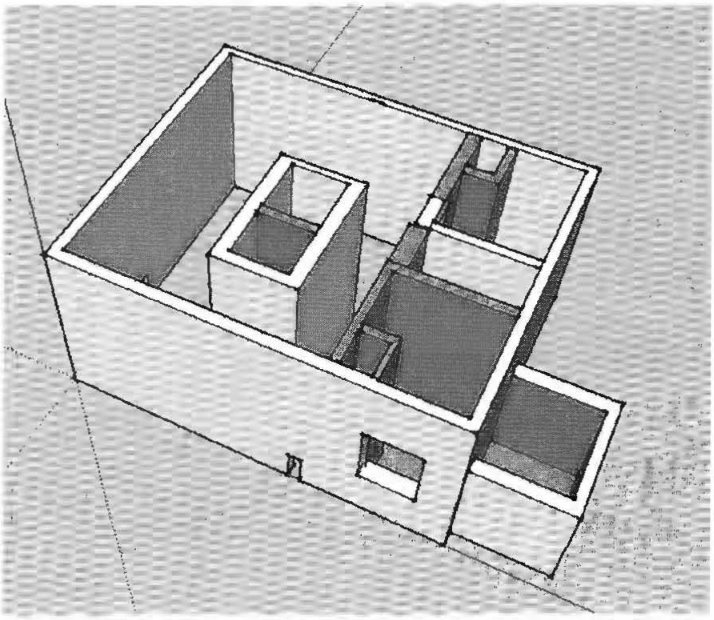
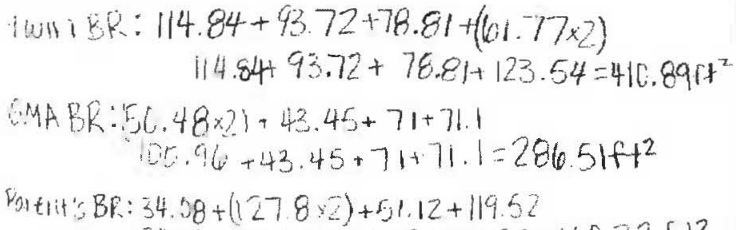


**Figure 6**. *The computation below is a sample student response to question 3.*




## Presentation Day with Final Reflections

On presentation day, group members set up stations that were visited by peers, an architect who designed the school's building, the district's mathematics curriculum specialist and teachers from the building. Groups were also given time to view classmates' presentations. As they critiqued their peers' work, they completed feedback sheets that included "a plus and a wish." Student feedback showcased a new understanding of architecture and included these comments: "The kitchen is too long and skinny," "I would have the man cave separate from the living room," "They should have explained more how they found the dimensions, etc," and "More open space is needed from kitchen to living room."

The stakeholders and teacher then evaluated student presentations using a checklist aligned directly to the assignment. During the presentations, we found that students were able to clearly articulate their mathematical understanding along with their reasoning for their design decisions.

After the presentations concluded, the architect gave feedback to help improve the overall designs. He suggested that students could measure the dimensions of their own home so that they could better understand the typical ratio between the area of a kitchen and a living room. Another suggestion was to allow students to look at blueprints of a house to deepen their understanding of scale and proportions

**Figure 7**. *Question 6 answers connected mathematics, art and engineering.*

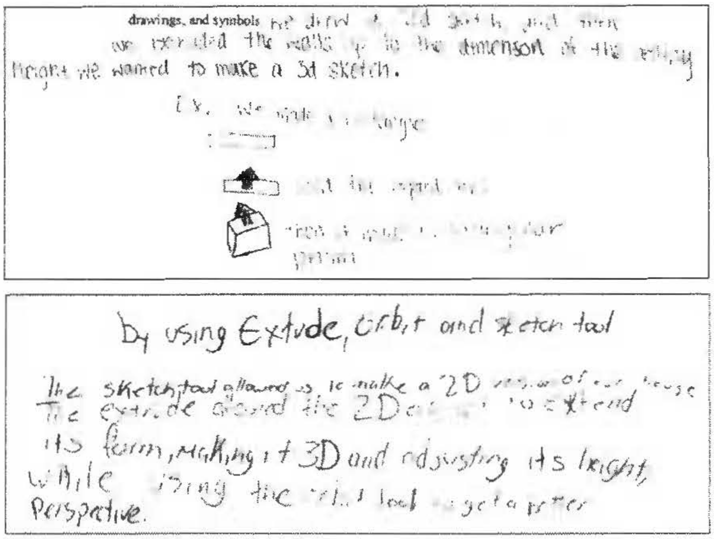
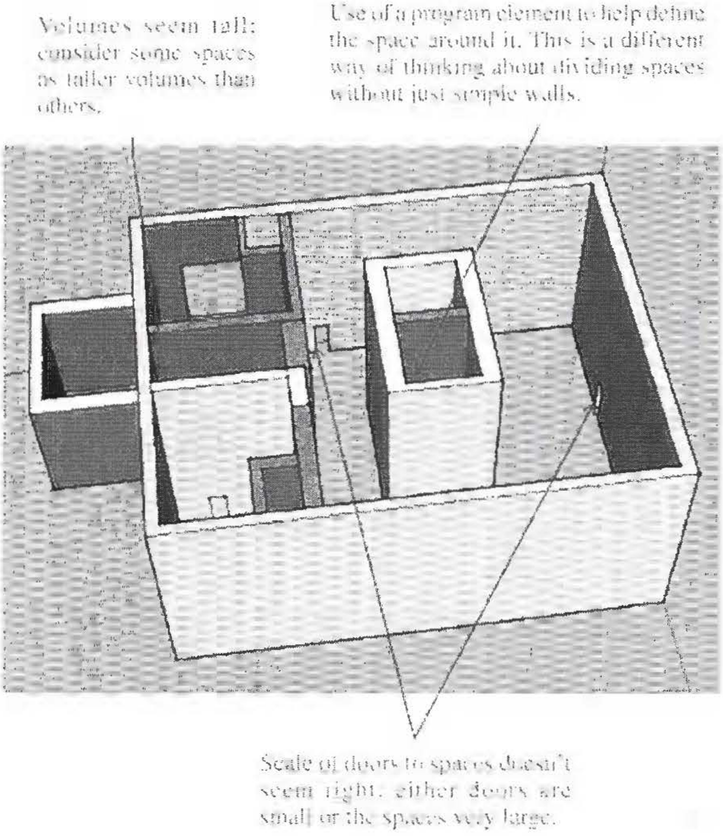



**Figure 8**. Architect feedback helped students improve previous math log responses.




before using SketchUp. Following the presentations, students reflected on what they had learned from this project (supported by Math Log questions 11–14). These culminating questions addressed several take-aways, including the advantages of continuously using feedback to make iterative improvements to one's design. To tie the work to the mathematics, students were asked to articulate what mathematics architects must know, questions 13 and 14 (see Table 1).

## A Meaningful Context for Integrating Technology

This Architecture Design Project provided a meaningful context for working with area, surface area, volume, ratios and proportional thinking, number sense and the integration of technology. Students were motivated and engaged, and they greatly valued the video information and feedback from a practising architect. The practising architect on our author team emphasized to students the importance of being able to use SketchUp and other technology tools as an important skill for their future careers in the 21st century. In addition to the focus on mathematics, this transdisciplinary project incorporated key elements of engineering design, art and technology, and it offered an avenue for the classroom teacher to showcase the work of her students to multiple stakeholders. We are hopeful that reading about this project inspires other middle-grades teachers to explore architecture and integrate mathematics with other content areas in support of authentic mathematics applications in concert with individuals working in these professions.

**Table 1**. *Student responses to questions 13 and 14 focused on the mathematics that architects must know to do their jobs.*

| 13. What mathematics do architects need to know to do their job well? | 14. What mathematics questions would I ask an architect to determine whether he or she should be hired for the job? |
|---|---|
| Ratio, area, surface area, volume, width, length, height, thickness (of walls), dimensions and so on. | • What are the dimensions of the house?<br>• What is the volume of each room?<br>• How would you scale the house in a model? |
| The essential mathematics architects must know how to do their job is how to find the square footage, volume and making the rooms the right size for its occupants. | • How do you find dimensions?<br>• How do you find the surface area?<br>• How tall do doors need to be? |
| • Square foot<br>• Cubic foot<br>• Conversion between measurements<br>• Ratios | How big do you think the master bathroom should be in relation to the master bedroom? |
| They need to know standard dimensions and the height walls should be in relation to people. | What square footage and volume would meet the standards of the area (plot of land) the house will be built on? |

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